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Summary of Higgs coupling measurements with staged running of ILC at 250 GeV, 500 GeV and 1 TeV

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In this note we summarized the Higgs coupling measurements mostly based on the ILD full simulation studies. Staged running of ILC is considered and turns out to be crucial to get the best understanding of the absolute normalization of all the couplings and Higgs total width. Both the canonical scenario and luminosity upgraded scenario are presented. This note is mainly prepared as the supporting material for the Snowmass Higgs white paper.

THIS IS A PRE-SUBMISSION OF AN UPCOMING NOTE DESCRIBING THE HIGGS SUMMARY INCLUDING UPDATED RESULTS FOR SNOWMASS STUDY

I. CANONICAL PHYSICS PROGRAM OF ILC

The International Linear Collider is well known for its capability of staged running, starting from 250 GeV, fully running at 500 GeV and upgradable to 1 TeV. 250 GeV is the optimal energy for the Higgs production through the Higgs-strahlung $e^+e^- \to ZH$, which is most important to get the precision measurements of Higgs mass, spin, CP nature, coupling of Higgs to ZZ and various branching ratios. At 500 GeV, it fully opens up another Higgs production channel through $e^+e^- \to \nu\bar{\nu}H$ from WW-fusion, which is crucial to get the coupling of Higgs to WW, hence the accurate test of the SU(2) nature together with HZZ coupling and the absolute normalization of Higgs total width and Higgs couplings to other particles. There are at least another two essential motivations at 500 GeV, one of which is the double Higgs production through $e^+e^- \to ZHH$ for the Higgs self-coupling study, and the other is the process of $e^+e^- \to t\bar{t}H$ for the top-Yukawa coupling study. Eventually going to 1 TeV, we would be able to produce the heavier new particle predicted by models beyond the Standard Model, to investigate the W_LW_L scattering for strong interaction sector, and to improve all the Higgs couplings to ultimate precisions. This has been well explained in the reference [1, 2].

The integrated luminosity assumed for the canonical physics program is 250 fb^{-1} at 250 GeV, 500 fb^{-1} at 500 GeV and 1000 fb^{-1} at 1TeV. The beam polarisation of electron and positron, P(e^-, e^+) , is (-0.8,+0.3) at 250 GeV and 500 GeV, and is (-0.8,+0.2) at 1 TeV.

II. INDEPENDENT MEASUREMENTS OF $\sigma \times$ Br

In experiment, what we can directly measure is the cross section of production channel, either Higgs-strahlung $e^+e^- \to ZH$ or WW-fusion $e^+e^- \to \nu\bar{\nu}H$, times the branching ratio of some specific decay, which we discuss here is Higgs to $b\bar{b}$, $c\bar{c}$, gg, $\tau^+\tau^-$, $\mu^+\mu^-$, WW^*, ZZ^* or $\gamma\gamma$. Table I summarizes the precisions on various independent $\sigma \times$ Br measurements assuming the running scenarios of previous section and Higgs mass of 125 GeV with the branching ratios from the Handbook of LHC Higgs Cross Section Working Group. It's worth mentioning that there are always two production channels at each energy:

- Higgs-strahlung production dominates at 250 GeV. Most of the measurements at this energy are focusing on the $\sigma_{ZH} \times$ Br, however the one $\sigma_{\nu\bar{\nu}H} \times$ Br$(H \to b\bar{b})$ for WW-fusion though not precisely measured is crucial to get the initial Higgs total width measurement at 250 GeV. Other decay modes for WW-fusion will not have large contribution to the global fit.
- Higgs-strahlung production and WW-fusion production are comparable at 500 GeV. Measurements from both channel are given and will contribute to global fit in a similar level.

	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$				
$\sqrt{s}$ and $\mathcal{L}$ (P_{e^-}, P_{e^+})	$250\,\mathrm{fb}^{-1}$ at 250 GeV (-0.8,+0.3)		$500\,\mathrm{fb}^{-1}$ at 500 GeV (-0.8,+0.3)		$1\,\mathrm{ab}^{-1}$ at 1 TeV (-0.8,+0.2)
mode	ZH	$\nu\bar{\nu}H$	ZH	$\nu\bar{\nu}H$	$\nu\bar{\nu}H$
$H \to bb$	1.2%	10.5%	1.8%	0.66%	0.32%
$H \to c\bar{c}$	8.3%	-	13%	6.2%	3.1%
$H \to gg$	7.0%	-	11%	4.1%	2.3%
$H \to WW^*$	6.4%	-	9.2%	2.4%	1.6%
$H \to \tau^+\tau^-$	4.2%	-	5.4%	9.0%	3.1%
$H \to ZZ^*$	19%	-	25%	8.2%	4.1%
$H \to \gamma\gamma$	29-38%	-	29-38%	20-26%	7-10%
$H \to \mu^+\mu^-$	-	-	-	-	31%
$H \to$ Inv.(95%$C.L.$)	$< 0.95\%$		-		-
$t\bar{t}H, H \to b\bar{b}$	-		28%		6.0%

TABLE I: Expected accuracies for cross section times branching ratio measurements for the 125 GeV H boson by the canonical scenario.

- WW-fusion production dominates at 1 TeV. Hence only the measurements for WW-fusion are given.

Since not all of those numbers in the table are directly from analyses done with Higgs mass of 125 GeV, I will explain in the following how they come from, either a straightforward extrapolation or a guesstimate.

A. At 250 GeV

- $\sigma_{ZH} \times \mathrm{Br}(H \to b\bar{b})$, $\sigma_{ZH} \times \mathrm{Br}(H \to c\bar{c})$ and $\sigma_{ZH} \times \mathrm{Br}(H \to gg)$ are extrapolated from the full simulation analysis [3] done with Higgs mass of 120 GeV. This extrapolation is rather straightforward, keeping the same number of background and scaling accordingly the number of signal events. This doesn't include the possible better background separation due to the higher Higgs mass and is hence conservative.
- $\sigma_{ZH} \times \mathrm{Br}(H \to \tau^+\tau^-)$ is extrapolated in a similar way based on the full simulation analysis [4] done with Higgs mass of 120 GeV.
- $\sigma_{ZH} \times \mathrm{Br}(H \to WW^*)$ is extrapolated in a similar way based on the full simulation analysis [5] done with Higgs mass of 120 GeV.
- for $\sigma_{ZH} \times \mathrm{Br}(H \to ZZ^*)$, there's not yet simulation analysis, but since the final states are similar to the $\sigma_{ZH} \times \mathrm{Br}(H \to WW^*)$ process, from which we estimate the number of signal and background events. For the $ZZ^* \to$ 4jets modes, we assume same background and same signal efficiency as those in $WW^* \to$ 4jets analysis. For the $ZZ^* \to l^+l^-$ + 2jets mode, we assume similar isolated-lepton selection efficiency, on-shell Z mass cut efficiency and Higgs mass cut efficiency as those in $ZH \to l^+l^-b\bar{b}$ analysis, and assume the background efficiency of $l^+l^-q\bar{q}$ to be half of $l\nu qq$ efficiency in $WW^* \to l\nu qq$ analysis. [**going to be replaced by full simulation study**]
- $\sigma_{ZH} \times \mathrm{Br}(H \to \gamma\gamma)$ is a guesstimate from old fast simulation study [6] and preliminary full simulation study [7]. [**going to be replaced by finalized full simulation study soon**]
- $\sigma_{ZH} \times \mathrm{Br}(H \to \mathrm{Inv.})$ is directly from the full simulation analysis [8].
- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to b\bar{b})$ is directly from the full simulation analysis [9].

B. At 500 GeV

- results from the ZH production are extrapolated from those at 250 GeV, by scaling both the signal and background events. For those from template fitting ($b\bar{b}, c\bar{c}, gg$), the scaling is first to get number of signal and background events before template fitting and then to extrapolate the results according to enhanced statistical significance of the template fitting.

- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to b\bar{b})$, $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to c\bar{c})$ and $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to gg)$ are extrapolated from the full simulation analysis [9–11] done with Higgs mass of 120 GeV, by scaling only the signal events.
- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to WW^*)$ is extrapolated from the full simulation analysis [11] done with Higgs mass of 120 GeV.
- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to \tau^+\tau^-)$ is from guesstimate. Very conservative signal efficiency is assumed (10%). The relative background efficiency for $\nu\bar{\nu}Z$ is estimated from $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to b\bar{b})$ analysis (the mass cut) and is doubled to be conservative. The relative background efficiency for W^+W^- is estimated from $\sigma_{ZH} \times \mathrm{Br}(H \to \gamma\gamma)$analysis, where the cut of angle between two taus is considered in a similar way to angle between two photons in $ZH \to \nu\bar{\nu}\gamma\gamma$ analysis. [**going to be replaced by full simulation study soon**]
- for $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to ZZ^*)$, the 4jets mode is extrapolated from $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to WW^*)$ analysis. In the final state of $ZZ^* \to l^+l^-qq$ mode, there are two isolated-leptons, large missing energy, and two jets from one on-shell Z. This mode is expected to be very clean without background. Efficiencies of isolated-leptons selection, missing energy cut and Z mass cut are estimated according to the similar cut in full simulation study.
- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to \gamma\gamma)$ is guesstimated from the $ZH \to \nu\bar{\nu}\gamma\gamma$ full simulation study. Since the kinematics are very different for ZH production and $\nu\bar{\nu}H$ production, every conservative efficiencies are assumed in this guesstimate. [**going to be replaced by full simulation study soon**]
- $\sigma_{t\bar{t}H} \times \mathrm{Br}(H \to b\bar{b})$ is extrapolated from the fast simulation analysis [12] done with Higgs mass of 120 GeV. [**going to be replaced by full simulation study soon**]

C. At 1 TeV

- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to b\bar{b})$, $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to c\bar{c})$ and $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to gg)$ are directly from the preliminary full simulation analysis [13] done with Higgs mass of 125 GeV. [**going to be replaced by finalized full simulation study soon**]
- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to WW^*)$ is directly from the preliminary full simulation analysis [13] done with Higgs mass of 125 GeV. [**going to be replaced by finalized full simulation study soon**]
- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to \tau^+\tau^-)$, $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to ZZ^*)$, $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to \gamma\gamma)$ are extrapolated from those at 500 GeV by scaling both the signal and background events.
- $\sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to \mu^+\mu^-)$ is directly from the full simulation analysis [14] done with Higgs mass of 125 GeV.
- $\sigma_{t\bar{t}H} \times \mathrm{Br}(H \to b\bar{b})$ is directly from the full simulation analysis [15] done with Higgs mass of 125 GeV.

III. MODEL INDEPENDENT GLOBAL FIT

In addition to all the independent cross section times branching ratio measurements, there is one more absolute cross section measurement of $e^+e^- \to ZH$[16, 17] which is done with Higgs mass of 120 GeV. The extrapolated precision of σ_{ZH} is 2.6% for Higgs mass of 125 GeV. This measurement is the key and flagship measurement at ILC which makes the absolute coupling and Higgs total width measurable in a totally model independent way.

Before discussing the global fit, it would be helpful to show an example explaining how we get the absolute couplings and Higgs total width. Let's look at the following four independent measurements:

$$\begin{aligned}
Y_1 &= \sigma_{ZH} = F_1 \cdot g^2_{HZZ} \\
Y_2 &= \sigma_{ZH} \times \mathrm{Br}(H \to b\bar{b}) = F_2 \cdot \frac{g^2_{HZZ} g^2_{Hbb}}{\Gamma_0} \\
Y_3 &= \sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to b\bar{b}) = F_3 \cdot \frac{g^2_{HWW} g^2_{Hbb}}{\Gamma_0} \\
Y_4 &= \sigma_{\nu\bar{\nu}H} \times \mathrm{Br}(H \to WW^*) = F_4 \cdot \frac{g^4_{HWW}}{\Gamma_0},
\end{aligned}$$

couplings	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
g_{HZZ}	1.3%	1.3%	1.3%
g_{HWW}	4.8%	1.4%	1.4%
g_{Hbb}	5.3%	1.8%	1.5%
g_{Hcc}	6.8%	2.9%	2.0%
g_{Hgg}	6.4%	2.4%	1.8%
$g_{H\tau\tau}$	5.7%	2.4%	1.9%
$g_{H\gamma\gamma}$	18%	8.4%	4.1%
$g_{H\mu\mu}$	-	-	16%
g_{Htt}	-	14%	3.2%
Γ_0	11%	5.9%	5.6%

TABLE II: Expected accuracies of Higgs couplings and total Higgs width by the canonical scenario.

where Γ_0 is the Higgs total width, g_{HZZ}, g_{HWW}, and g_{Hbb} are respectively the coupling of Higgs to ZZ, WW and $b\bar{b}$, F_1, F_2, F_3 and F_4 are the factors we can exactly calculate. It's rather straightforward to get the couplings with the following steps:

i.) from measurement Y_1 we can get the coupling g_{HZZ}.

ii.) from the ratio Y_2/Y_3 we can get the coupling ratio g_{HZZ}/g_{HWW}.

iii.) with g_{HZZ} and g_{HZZ}/g_{HWW}, we can get g_{HWW}.

iv.) once we know g_{HWW}, from measurement Y_4 we can get the Higgs total width Γ_0.

v.) once we know g_{HZZ}, g_{HWW} and Γ_0, from measurement Y_2 or Y_3 we can get g_{Hbb}.

This example already gave quite clear synergy between the two main Higgs production channels. The best energy to investigate the Higgs-strahlung production $e^+e^- \to ZH$ is around 250 GeV, however the WW-fusion production $e^+e^- \to \nu\bar{\nu}H$ at 250 GeV is very small. WW-fusion production will be fully open at 500 GeV with cross section of one order larger. This is one essential motivation to go to higher energy after running at 250 GeV.

A. Coupings Precisions by Global Fit

So far we have 32 independent $\sigma \times$ Br measurements from Table I, each of which, Y_i, can be predicted as $Y_i' = F_i \cdot \frac{g^2_{HZZ} g^2_{HXX}}{\Gamma_0}$, or $Y_i' = F_i \cdot \frac{g^2_{HWW} g^2_{HXX}}{\Gamma_0}$, or $Y_i' = F_i \cdot \frac{g^2_{Htt} g^2_{HXX}}{\Gamma_0}$, $i = 1, 2, ..., 32$, where XX means some specific decay particle from Higgs and F_i is some certain factor corresponding to the decay. And we have one absolute cross section measurement $Y_{33} = \sigma_{ZH}$ which can be predicted as $Y_{33}' = F_{33} \cdot g^2_{HZZ}$. In total we have 33 independent measurements and what we want to know in physics is the 9 fundamental couplings, HZZ, HWW, Hbb, Hcc, Hgg, $H\tau\tau$, $H\mu\mu$, Htt and $H\gamma\gamma$, and the Higgs total width, Γ_0. Our strategy is to construct a χ^2 which is defined as following

$$\chi^2 = \sum_{i=1}^{i=33} (\frac{Y_i - Y_i'}{\Delta Y_i})^2,$$

where Y_i is the measured value, ΔY_i is the error Y_i and Y_i' is the predicted value which can always be written with several of those couplings and Higgs total width. So this χ^2 has actually 10 parameters. The next step is quite straightforward, to minimize this χ^2. Here we assume all the 9 couplings and Higgs total width are free parameters without any correlation. The result from the minimization is given in the last column of Table II, which is the error of each parameter. To compare the capabilities at different running stage of ILC, in Table II the expected precisions at 250 GeV only and at both 250 GeV and 500 GeV are also shown in the second and third columns.

B. Cross Section and Branching Ratios by Global Fit

Alternatively, in the χ^2 of global fit, we can also use 3 cross sections, σ_{ZH}, $\sigma_{\nu\bar{\nu}H}$ and $\sigma_{t\bar{t}}H$, and 8 branching ratios, $\mathrm{Br}(H \to b\bar{b})$, $\mathrm{Br}(H \to c\bar{c})$, $\mathrm{Br}(H \to gg)$, $\mathrm{Br}(H \to WW^*)$, $\mathrm{Br}(H \to ZZ^*)$, $\mathrm{Br}(H \to \tau^+\tau^-)$, $\mathrm{Br}(H \to \mu^+\mu^-)$ and

Branching Ratios	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
σ_{ZH}	2.6%	2.6%	2.6%
$\sigma_{\nu\bar{\nu}H}$	11%	2.8%	2.8%
$H \to b\bar{b}$	2.9%	2.8%	2.8%
$H \to c\bar{c}$	8.7%	5.3%	3.8%
$H \to gg$	7.5%	4.3%	3.3%
$H \to WW^*$	6.9%	3.5%	3.0%
$H \to \tau^+\tau^-$	4.9%	4.0%	3.4%
$H \to ZZ^*$	19%	7.7%	4.5%
$H \to \gamma\gamma$	34%	17%	8.0%
$\sigma_{t\bar{t}H}$	-	28%	6.5%
$H \to \mu^+\mu^-$	-	-	31%

TABLE III: Expected accuracies of Higgs branching ratios and production cross sections by the canonical scenario.

	$\Delta(\sigma \cdot BR)/(\sigma \cdot BR)$				
$\sqrt{s}$ and $\mathcal{L}$	$1150\,\text{fb}^{-1}$ at $250\,\text{GeV}$		$1.6\,\text{ab}^{-1}$ at $500\,\text{GeV}$		$2.5\,\text{ab}^{-1}$ at $1\,\text{TeV}$
(P_{e^-}, P_{e^+})	(-0.8,+0.3)		(-0.8,+0.3)		(-0.8,+0.2)
mode	ZH	$\nu\bar{\nu}H$	ZH	$\nu\bar{\nu}H$	$\nu\bar{\nu}H$
$H \to b\bar{b}$	0.56%	4.9%	1.0%	0.37%	0.20%
$H \to c\bar{c}$	3.9%	-	7.2%	3.5%	2.0%
$H \to gg$	3.3%	-	6.0%	2.3%	1.4%
$H \to WW^*$	3.0%	-	5.1%	1.3%	1.0%
$H \to \tau^+\tau^-$	2.0%	-	3.0%	5.0%	2.0%
$H \to ZZ^*$	8.8%	-	14%	4.6%	2.6%
$H \to \gamma\gamma$	16%	-	19%	13%	5.4%
$H \to \mu^+\mu^-$	-	-	-	-	20%
$H \to$ Inv.$(95\%C.L.)$	$< 0.37\%$		-		-
$t\bar{t}H, H \to b\bar{b}$	-		16%		3.8%

TABLE IV: Expected accuracies for cross section times branching ratio measurements for the 125 GeV H boson by the luminosity upgrade scenario.

Br($H \to \gamma\gamma$), to predict the expected values Y_i'. And if we assume all of these 11 parameters are independent, the minimization of χ^2 gives how well we could measure the cross sections and branching ratios, which is shown in Table III.

C. Comments to the Global Fit

In the above global fit, certainly it is totally model independent. The upper limit of invisible decay didn't enter the global fit. Here we would like to point out that this global fit is rather conservative, because some of the free parameters in the Standard Model are actually highly correlated. For example, the loop couplings $H\gamma\gamma$ and Hgg mostly depend on the Htt and HWW couplings; the Higgs total width is the sum of partial width. If we could add these constraints to the global fit, the couplings would be much more precisely constrained, which is shown in the reference [18] though in a very mild model dependent way.

IV. LUMINOSITY UPGRADE

The luminosities assumed in the canonical program are rather conservative. There's a proposal [19] which would significantly increase the luminosities at each running stage. In this note we would like to give also the prospects of the coupling precisions assuming the upgraded luminosities, which are 1150 fb^{-1} at 250 GeV, 1600 fb^{-1} at 500 GeV and 2500 fb^{-1} at 1 TeV. The expected precisions of cross section times branching ratio are summarized in Table IV. The couplings and branching ratios by global fit are given in Table V and VI.

couplings	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
g_{HZZ}	0.61%	0.61%	0.61%
g_{HWW}	2.3%	0.67%	0.65%
g_{Hbb}	2.5%	0.90%	0.74%
g_{Hcc}	3.2%	1.5%	1.1%
g_{Hgg}	3.0%	1.3%	0.93%
$g_{H\tau\tau}$	2.7%	1.2%	0.99%
$g_{H\gamma\gamma}$	8.2%	4.5%	2.4%
$g_{H\mu\mu}$	-	-	10%
g_{Htt}	-	7.8%	2.0%
Γ_0	5.4%	2.8%	2.7%

TABLE V: Expected accuracies of Higgs couplings and total Higgs width by the luminosity upgrade scenario.

Branching Ratios	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
σ_{ZH}	1.2%	1.2%	1.2%
$\sigma_{\nu\bar{\nu}H}$	5.1%	1.3%	1.3%
$H \to b\bar{b}$	1.3%	1.3%	1.3%
$H \to c\bar{c}$	4.0%	2.7%	2.0%
$H \to gg$	3.5%	2.2%	1.7%
$H \to WW^*$	3.2%	1.8%	1.5%
$H \to \tau^+\tau^-$	2.3%	2.0%	1.7%
$H \to ZZ^*$	8.9%	4.1%	2.5%
$H \to \gamma\gamma$	16%	8.8%	4.8%
$\sigma_{t\bar{t}H}$	-	16%	3.9%
$H \to \mu^+\mu^-$	-	-	20%

TABLE VI: Expected accuracies of Higgs branching ratios and production cross sections by the luminosity upgrade scenario.

A. Power of Staged Running

Within either the canonical or luminosity upgrade scenario, we have already seen the significant benefit from the staged running. To be even more convincing, we plotted the precisions of coupling as a function of running time at 250 GeV under the assumption that there will be in total 10 years of running at 250 GeV and 500 GeV. Figure 1 (left) is for the HWW coupling and Higgs total width Γ_0. Figure 1 (right) is for Hbb, Hcc and Hgg couplings. And Figure 2 is for all the couplings and Higgs total width together. There in those plots the two ends corresponding to running at 250 GeV only (upper-end) and running at 500 GeV only (lower-end). It's very clear that the best scenario is staged running at both 250 GeV and 500 GeV. And the optimal running time for different coupling is different, which means eventually the optimal running time will depend on which coupling is the one we are most interested in.

V. HIGGS SELF-COUPLING

To probe the Higgs self-coupling is certainly another very important task which need to be addressed at ILC. We would like to summarize also the studies on Higgs trilinear self-coupling based on the full simulation of ILD at ILC [20]. The study in reference [20] is done with Higgs mass of 120 GeV and here we show the results extrapolated to Higgs mass of 125 GeV. Three scenarios are considered, the canonical scenario (I), the luminosity upgrade scenario (II) and the scenarios (III) of 6 years running at 500 GeV and 6 years running at 1 TeV. The expected precisions of Higgs self-coupling corresponding to those three scenarios are shown in Table VII. The result at 1 TeV has already combined the contributions of ZHH at 500 GeV, ZHH at 1 TeV and $\nu\bar{\nu}HH$ at 1 TeV. The conclusion is ILC has the capability to determine the trilinear Higgs self-coupling with a precision of 10%. It's worth emphasizing that this conclusion is all based on the full simulation study and using the analysis technology we have known now.

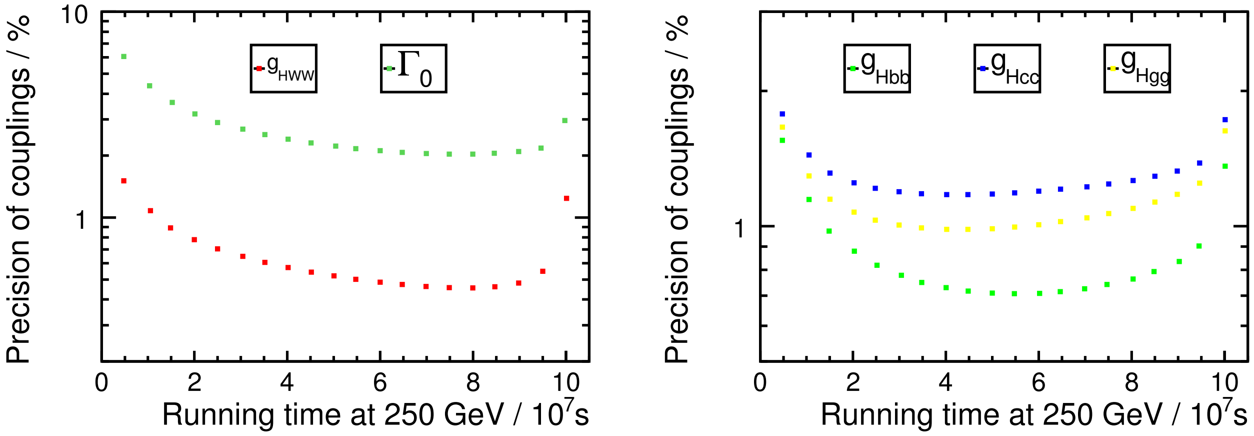

FIG. 1: The expected precision of couplings as a function of running time at 250 GeV assuming in total 10 years of running at 250 GeV and 500 GeV. Left: HWW coupling and Higgs total width Γ_0; right: Hbb, Hcc and Hgg couplings.

$\Delta\lambda/\lambda$	500 GeV	500 GeV + 1 TeV
Scenario I.	104%	26%
Scenario II.	58%	16%
Scenario III.	41%	11%

TABLE VII: Expected accuracies of Higgs trilinear self-coupling. The three scenarios are explained in text.

A. Projections

Since in the study [20] we have only investigated one decay mode of the two Higgs, both to $b\bar{b}$, there's still large room to get better result by studying the decay mode $HH \to b\bar{b}WW^*$ which has already been ongoing [21]. The preliminary study has suggested a relative 20% improvement to the Higgs self-coupling. Regarding the analysis technology, there's study about the improvement of the jet-clustering which is mini-jet based color-singlet clustering [22]. Using this jet-clustering it would be possible to further improve the Higgs self-coupling measurement around 20% relatively. The projections with these two improvements have been shown in Table VIII.

$\Delta\lambda/\lambda$	500 GeV			500 GeV + 1 TeV		
	(A)	(B)	(C)	(A)	(B)	(C)
Canonical	104%	83%	66%	26%	21%	17%
Luminosity UP	58%	46%	37%	16%	13%	10%

TABLE VIII: Projections of the Higgs self-couplings in both canonical scenario and luminosity upgraded scenario: (A) is current results from full simulation study of both Higgs to $b\bar{b}$; (B) is by adding $HH \to b\bar{b}WW^*$; (C) is by improving the analysis technology of mini-jet based color-singlet clustering.

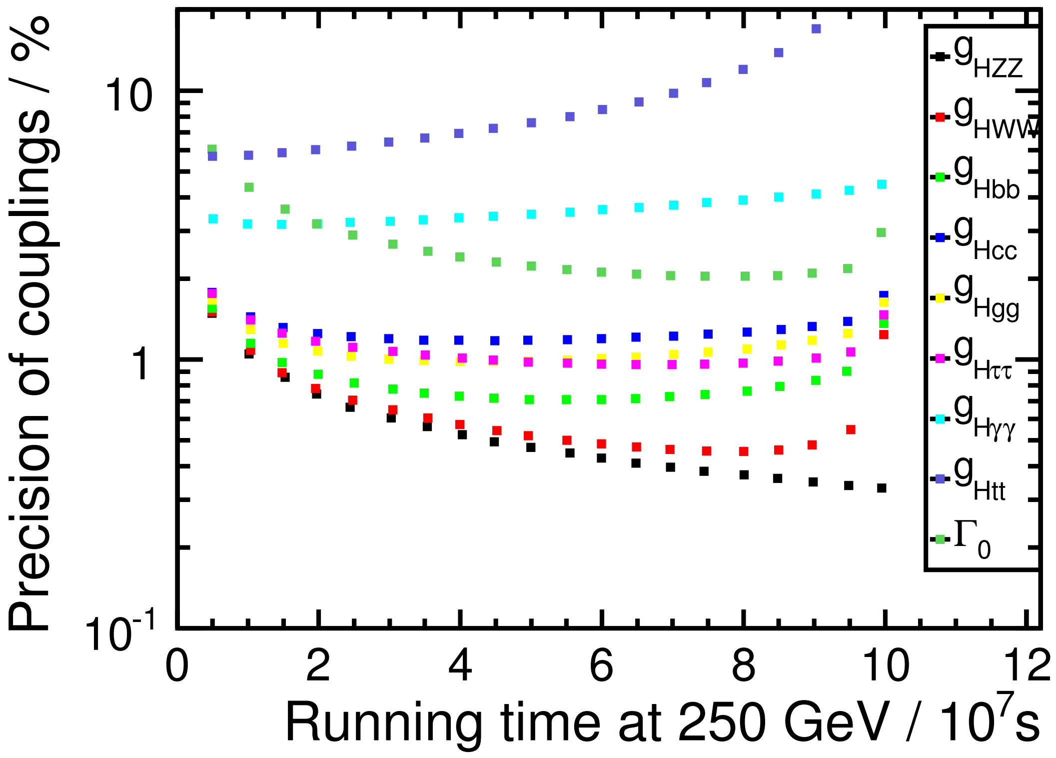

FIG. 2: The expected precision of couplings as a function of running time at 250 GeV assuming in total 10 years of running at 250 GeV and 500 GeV.

VI. SUMMARY

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